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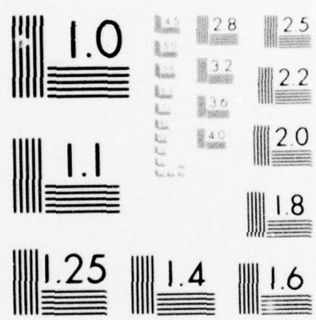
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FABRICATION OF THIN FILM MAGNETIC GARNET STRUCTURES FOR INTRA-CAVITY LASER APPLICATIONS

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By

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E. C. Whitcomb and R. D. Henry,
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micrometers

ABSTRACT

Garnet compositions similar to those used for bubble domain materials have been used to fabricate ferrimagnetic nonreciprocal devices for ring laser gyro biasing at 1.152 μm. Such devices are used inside an active laser cavity, therefore precise control of the optical and physical thickness of the films is required. Two concepts of Faraday elements have been demonstrated and new material and fabrication techniques have been developed to implement them. Operating Faraday elements with 0.5 percent insertion loss have been produced.

INTRODUCTION

One of the problems that has been encountered in using ring lasers as inertial gyroscopes is that phase-locking occurs for small angular velocities and hence the usual linear relation between mode-splitting and rotation rate is invalid. Present state-of-the-art solutions to this problem involve either introducing a real oscillating bias (mechanical dither) or the use of a nonreciprocal magnetic element. This paper describes the fabrication of thin film garnets for use as a nonreciprocal magnetic element at 1.152 μm. Such a device is unique as it is used inside of an active laser cavity. However, such utilization places extremely tight tolerances on all of the material parameters. The remainder of this paper will be devoted to describing the types of structures produced as Faraday elements and the fabrication techniques involved.

Faraday Elements

Two approaches to the development of Faraday elements will be presented in this paper. Both concepts are based on the unique use of thin film epitaxial garnet structures produced by liquid phase epitaxy (LPE). [1]

One of the structures produced as a Faraday element involves the use of a half wave of a suitable ferrimagnetic garnet and two quarter waves of MgF_2. This configuration is shown in Figure 1. The second type of structure looks more complicated but is actually easier to produce. [2] It consists of two epitaxial garnet antireflection coatings, each a quarter wave of a paramagnetic garnet, a multiple quarter wave of the appropriate ferrimagnetic garnet, and a quarter wave of MgF_2. This structure is shown in Figure 2.

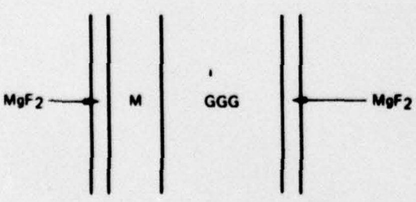


Fig. 1. Structure of a double layer Faraday element

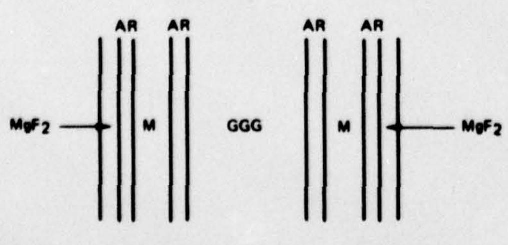


Fig. 2. Structure of a four layer Faraday element.

Selection of the ferrimagnetic garnet to be used in either case is dictated by the magnetic and magneto-optical requirements of the device. The modulation requirements of the Faraday elements limit the saturation magnetization to less than 2 Oe. The magneto-optical requirements of the garnet at 1.152 μm are:

Insertion Loss < 0.5%

Magneto-optic Figure of Merit > 60 deg

The ferrimagnetic garnet chosen for use in the simple structure of Figure 1 was $(YBi)_3(FeGa)_5O_{12}$. Films of this material were grown by LPE using a Bi_2O_3 - K_2O flux. [3] Film deposition was conducted over a temperature range of 790 to 810°C. Properties of a typical film of this composition used for a Faraday element are given in Table 1 for 1.15 μm.

Table I indicates that the absorption coefficient of this material is very low. This is an extremely important point as it was observed that the absorption coefficients of most garnet compositions with high bismuth substitution were rarely lower than 300 cm^{-1} at 1.152 μm. The use of Ca^{2+} was reported to be effective in reducing optical absorption in garnets grown from $PbO:PbF_2:B_2O_3$ flux. [4] We have used this charge compensation mechanism to reduce the absorption in epitaxial films of $(YBi)_3(FeGa)_5O_{12}$ and $(YBi)_3(FeAl)_3O_5$ grown from $Bi_2O_3:K_2O$ fluxes. By varying the Ca^{2+} content of the melt we found that α could be varied from 410 cm^{-1} to < 10 cm^{-1}. The lowest values of α were achieved with 1×10^{-3} mole percent $CaCO_3$ in the melt. It was also found that additions of $CaCO_3$ in excess of 2×10^{-3} mole percent caused the optical absorption to increase again to > 300 cm^{-1}.

TABLE I

Index of Refraction	2.19
Film Thickness	~3 μm
Saturation Switching Field	<10 Oe
Specific Faraday Rotation	200 deg/cm
Absorption Coefficient	<10 cm^{-1}
Lattice Misfit	0.003 Å

The multilayer garnet structure used for the second concept of the Faraday element required development of an epitaxial garnet anti-reflection coating. The LPE garnet system chosen for this effort was $(YGd)_3(FeGa)_5O_{12}$. We found that by varying the iron to gallium ratio and the rare earth content of the LPE melt we could readily vary the refractive index of this material from 2.0 to 2.12 while maintaining an acceptable lattice mismatch between the film and substrate. Figure 3 is a graph of index of refraction of $(YGd)_3(FeGa)_5O_{12}$ versus gallium content of the film. Having demonstrated that the index of the garnet could in fact be selected at will within this range, we then addressed the problem of growing very thin uniform films of the material. Calculations indicated that the AR coatings would have to be between 1000 Å and 2000 Å thick. This presented problems with accurate film measurements as well as film growth techniques. We found that conventional ellipsometry techniques employing a He-Ne laser were useful in determination of the film indices but the sample preparation necessary to use this method prevented its use for determining the film thicknesses of multilayer garnet structures. [5]

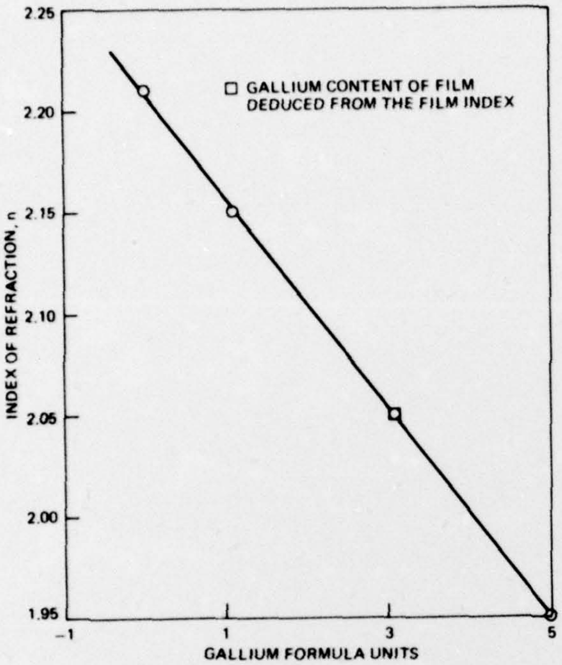


Fig. 3. Change in refractive index of $(YGd)_3(FeGa)_5O_5$ with change in gallium content.

Using transmission spectrophotometry, we were able to use quarter wave phenomena to determine optical thickness of very thin films as well as to determine the transmission coefficients of the completed Faraday elements.

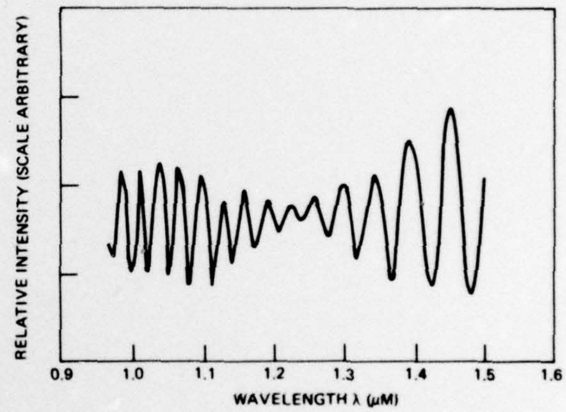
The garnet film depositions for the AR coatings were made using $PbO\text{-}B_2O_3$ flux in the temperature range 960 to 920°C. The films were grown at rates from 0.2 μm/min. to 0.8 μm/min., from an LPE flux system containing Y_2O_3, Gd_2O_3, Fe_2O_3, Ga_2O_3, PbO and B_2O_3 with mole percents of 0.14, 0.14, 3.82, 1.87, 88.29 and 5.74 respectively. It was found that film deposition rates below 0.3 μm/min. were not useful as the indices from film to film were not constant; therefore accurate thickness determination was difficult. Using automated film growth equipment, with 0.1 sec control on the substrate emersion sequence, it was possible to grow films within ±50 Å of the desired film thickness of 1250 Å.

The ferrimagnetic garnet film selected for use in this case was $(YLa)_3(FeGa)_5O_{12}$. This system was selected to avoid potential problems with a magnetic compensation point and high uniaxial anisotropy associated with elements such as gadolinium when M_s is ≈ 0. The properties of a typical Faraday element produced in this mode are listed in Table II.

TABLE II

Index of Refraction	2.11
Film Thickness	~3 μm
Saturation Switching Field	<10 Oe
Specific Faraday Rotation	200 deg/cm
Absorption Coefficient	<10 cm^{-1}
Transmission Coefficient	>0.995

Figure 4 is a spectrophotometer trace of a wafer which contains both an AR-coated garnet film and the same garnet film without an interfacial AR-coating. This was made by first depositing the thin AR-coating film, etching one half of the wafer with hot phosphoric acid and then depositing a thick magnetic garnet film onto the wafer. The trace for the AR-coated half is shown in Figure 4a and that for the single thick layer film is shown in Figure 4b. The important point of comparison of these traces is the change in intensity ΔI, of the beats at 1.23 μm. Figure 5 is a progressive sequence of spectrophotometry traces showing the increase in the transmission efficiency of the multiple layer garnet structure described in Table II as it was AR coated with MgF_2. The structure of this Faraday element is shown in Figure 2. This element consists of a duplicate structure on both sides of the substrate as compared to the single garnet film shown in Figure 1.



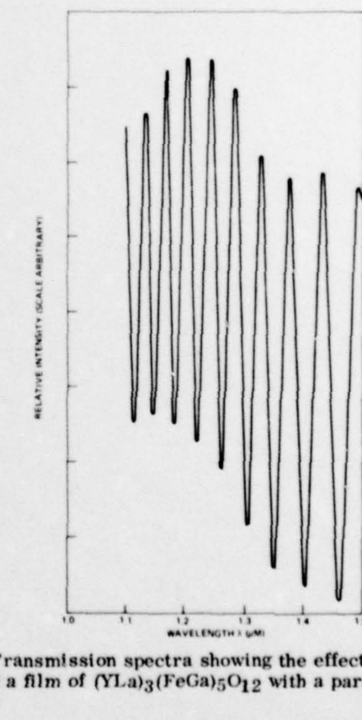


Fig. 4. Transmission spectra showing the effect of AR coating a film of $(YLa)_3(FeGa)_5O_{12}$ with a paramagnetic garnet.

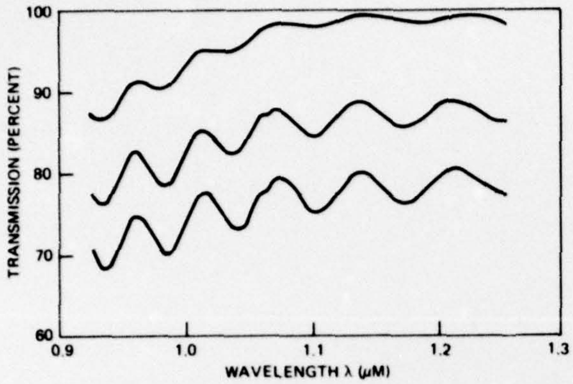


Fig. 5. Transmission spectra of the garnet structure as it was progressively AR coated with MgF_2.

CONCLUSIONS

The growth procedures outlined here have produced thin film magnetic elements which were inserted into an active cavity operating at 1.152 μm with two quarter wave plates. The bias depth obtained was equivalent to a physical rotation rate of 350 deg/sec and the total insertion loss was less than 1 percent with only 0.5 percent arising from the garnet element. Elements with as little as 0.1 percent insertion loss have been made using the four layer structure in Figure 2. Although we have limited this investigation to intra-cavity Faraday elements for ring laser gyros, the anti-reflection and absorption loss minimization concepts are applicable to several other intra-cavity devices that could be made using thin film garnets, such as modulators and stripe domain phase gratings.

ACKNOWLEDGEMENT

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